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Solar heat pump - Flamingohuset

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Abstract

This paper includes the results of measurements of a new modern low energy house which is heated with a solar heat pump system. The house construction is based on a build system where the outer wall consists of expanded polystyrene blocks that are filled with concrete and covered with plaster. The house has been completed in 2008/09, and inhabited by a family of two adults and two children.
The house is heated by a solar heat pump system denoted as “serial”. The heat pump extracts heat from the ground and supplies heat for space heating and domestic hot water. The solar thermal system heats a hot water storage and excess solar heat is transmitted to the ground. Additional sustainable installations are included in the house like mechanical ventilation with heat recovery, energy efficient lighting system, solar cell on the roof and a rain water system.
The energy consumption is measured during the last four years. There has been an extensive monitoring program where significant energy flow and temperatures are monitored. The system has been operating since 2009 and adjusted and improved so today the performance corresponds to the expectation. The yearly system performance factor SPF $_{SHP+}$ has been monitored to 2.79 in 2012.
The actual space heating consumption is larger than the estimated, but the indoor climate has been good. The PV system and the rain water system correspond to the expectation. The rainwater system has reduced the water consumption by 50 %.

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Keywords: Solar Heat Pump, Monitored System Performance Factor, Low energy house, Rain Water system, Photovoltaic.

1. Description of system

This paper includes the results of measurements of a new modern low energy house which is heated with a solar heat pump system. The house is a detached house in one floor level built as a modern low-energy house accordingly to the Danish Building Regulation of 2008 [2]. The house construction is based on a build system where the outer

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wall consists of expanded polystyrene blocks that are filled with concrete and covered with plaster. The house has been completed in 2008/09 and inhabited by a family of two adults and two children.

Fig. 1. Photo of the Flamingohuset, south façade.

The treated floor area is 166 m^2 and contains a living room, kitchen, 5 bedrooms, bathroom and a toilet. In autumn 2011, the residential area is increased to 200 square meters by utilising the attic. The house is located in Taulov in Jutland with a climate similar to the average in Denmark.

The house is a low energy house and insulated with approximately 400 mm insulation in the roof and floor and the walls have a total thickness of 400 mm with a U-value of 0.13 W/m^2K. The window area is 29.1 m^2 equivalent to 17.5 % of the treated floor area and the average U-value of windows and doors is 1.15 W/m2K. The house is ventilated by mechanical ventilation with heat recovery. The house is heated by a floor heating system with a flow temperature of 40 °C.

The house specific transmission loss is 3.9 W/m^2 and the annual energy needs for space heating is estimated to 18.0 kWh/m^2 (heated floor area). The energy demand for domestic hot water is 21.2 kWh/m^2 including losses from installations. The design hot water consumption is 250 l/m^2 per year and a tapping temperature of 50 ^oC.

Fig. 2. External wall consist of expanded polystyrene blocks filled with concrete and sealed by plaster.

The house is heated by a solar heat pump system with a nominal output of 6 kW and 8 m^2 solar collectors on roof. The heat pump delivers heat for space heating via a floor heating system and to a 300 litre hot water tank. The heat from the hot water tank can fed back to the space heating. The hot water storage acts as a storage tank for the heat pump and for the solar system. The heat pump uses the ground as the heat source. Excess heat from the collector is transferred to the ground and increases the temperature of the soil to improve the performance of the heat pump - COP. The heat pump is equipped with a 100 litre water tank for utilizing the superheated gas in the heat pump circuit.

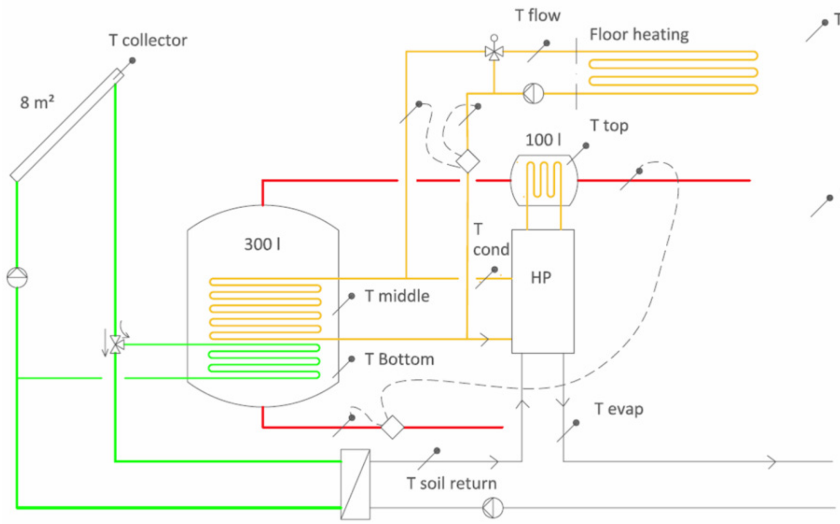

Fig. 3. Hydraulic scheme of the solar heat pump system.

A photovoltaic system of 1.72 kWp is installed on the south orientated roof. The yearly electricity output is designed for 1470 kWh (AC).

The house lighting system is based on LED with an advanced control system.

2. Monitoring

Detailed measurements of the house energy demands and the performance of the heating system exist as hourly values during a period from 2009 to 2012. There are measurements from 5 electrical power meters, 2 energy meters and 10 temperatures and the sunshine hour.

The measurements from year 2012 are shown in Table 1 as monthly value. The monitored electricity consumption of the heat pump (EL HP) includes all pumps and heating control system. All other electricity use (EL Basic) includes lighting, fans and electrical equipment installed in the house. The heat pump's total electricity consumption in 2012 was then 4044 kWh.

The electricity demand is delivered by solar cells (EL PV) and by the general electricity grid (EL GRID), a total of 8273 kWh during year 2012. The electricity production from the PV system has been 1987 kWh and it is 35 % more than estimated.

The heat consumption for space heating (SH) and domestic hot water (DHW) have been at 9420 kWh and 1867 kWh. The normalized space heating demand is 9343 kWh.

The seasonal performance factor [1] is calculated as:

$$SPF_{SHP+} = (9420 + 1867) / 4044 = 2.79 \text{ (2.77 normalized).}$$

The measured annual seasonal performance factor has been 2.79 in 2012.

Monthly values of the SPF_{SHP+} are shown on Fig. 4. The factor is not shown for the summer months of June, July and August when both heat and electricity consumption is small and the uncertainty of the measurements has therefore a great effect on the performance factor in these months. It appears from the graph that increased solar radiation during the months of April, May and August enhances the SPF_{SHP+} factor in these months.

Table 1. Monitored data (year 2012)

	Electricity use			Electrity production			Heat consumption		
	El basic kWh	EL HP kWh	Sum kWh	EL PV kWh	EL GRID kWh	Sum kWh	SH kWh	DHW kWh	Sum
Jan	369	817	1186	67	1119	1186	2014	148	2162
Feb	378	793	1171	93	1078	1171	1806	150	1956
Mar	315	352	667	205	462	667	841	127	968
Apr	366	163	529	228	301	529	514	68	582
May	335	128	463	286	177	463	248	256	504
Jun	368	70	437	244	194	438	54	146	200
Jul	318	49	367	270	97	367	0	82	82
Aug	335	27	362	261	101	362	0	146	146
Sep	311	102	413	157	256	413	155	151	306
Oct	321	287	608	119	489	608	758	170	928
Nov	378	476	855	46	809	855	1318	236	1554
Dec	437	779	1215	12	1204	1215	1712	187	1899
Year	**4229**	**4044**	**8273**	**1987**	**6286**	**8273**	**9420**	**1867**	**11287**

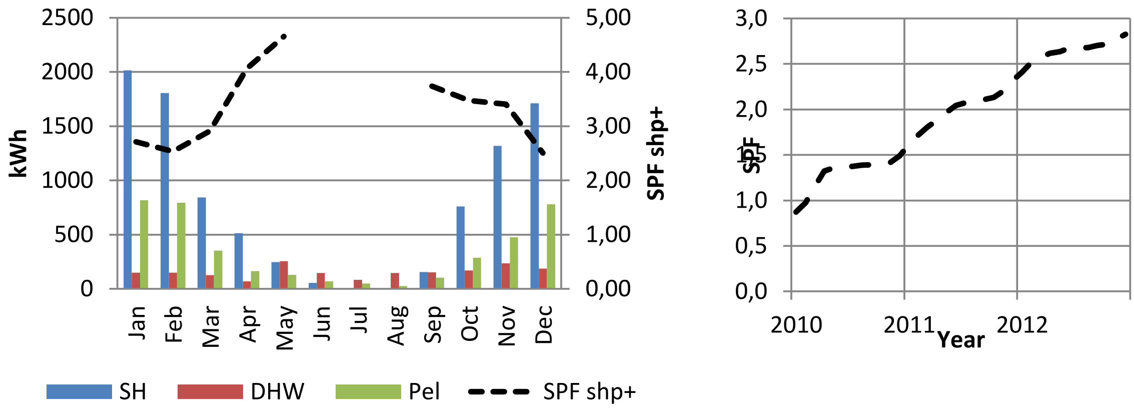

Fig. 4. Left: Monitored data of the space heating (SH), domestic hot water (DHW) and heat pump electricity (Pel). Right: The development of the system performance factor during the period from 2010 to 2012.

There have been commissioning problems during the first years of operation. The system has been adjusted and several parts of the system are replaced. Recently, the heat pump is replaced in March/April 2012. This has meant that the system performance factor has constantly improved. The development of the system performance factor is plotted in Fig. 4 and shows that the seasonal SPF has increased from 0.90 to 2.77. The seasonal performance factor for 2012 is 2.79 and it is expected that it will be even higher when the new heat pump has been operating during a whole year.

3. Simulation

In order to get a building permit in Denmark the building energy performance must be documented through calculations. Energy from solar thermal and solar PV can be included in the calculations. The calculations of the thermal performance of the building follows the standard ISO 13790, which is a simple model based on monthly values. The space heating demand is calculated to 18.0 kWh/m^2. The net energy demand for domestic hot water excluding losses is calculated to 11.6 kWh/m^2. The estimated monthly values are shown in Fig. 5 together with the monitored values and yearly values are shown in Table 2.

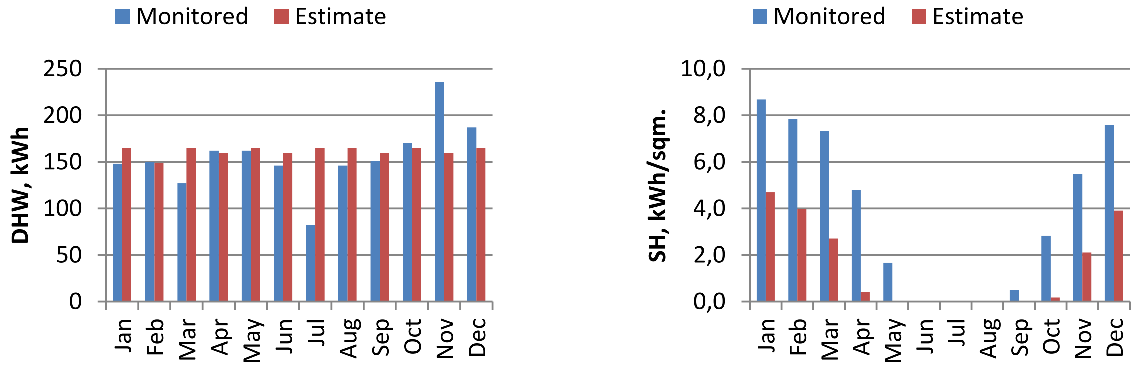

Fig. 5: Monitored and calculated energy consumption for domestic hot water (DHW) and space heating (SH). The monitored data are from 2012.

Table 2: Yearly data (year 2012) of the monitored and calculated energy consumptions. The monitored space heating is normalised accordingly to an average year and the heated floor is 200 m^2.

	Estimated (166m^2)		Monitored (200m^2)	
	[kWh]	[kWh/m^2]	[kWh]	[kWh/m^2]
SH	2990	18,0	9343	46,7
DHW	1940	11,7	1867	9,3
SH+DHW	4930	29,7	11210	56,0
EL HP	2035		4044	
SPF $_{SHP+}$	2,42		2,77	

In autumn 2011, the residential area is increased from 166 to 200 square meters. As shown in the Table 2, there is a good correlation between measured and calculated energy demands for the domestic hot water. In contrast, the measured energy demands for space heating are more than two times larger than the calculated value. It is a significant difference and is not further verified in this report.

There is a reasonable correlation between the measured and calculated seasonal performance factor (SPF). The calculated heat pump performance does not include the effect of accumulated heat from the solar heating system in soil.

The results of the present monitoring program demonstrates a need for further development of solar heat pump calculation tool in order to achieve more reliable calculation of the solar heat pump system which also takes into account the accumulation of solar heat in the soil.

References

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[2] Danish Building Regulation BR08. Erhvers- og Byggestyrelsen, Denmark 2008.